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AN ANALYSIS OF FEEDING SYSTEM OF SUGAR PLANT SUBJECT TO COVERAGE FACTOR

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ABSTRACT

Feeding system is an important unit in sugar manufacturing plants. It comprises with the help of six components, namely unloader, cane carrier, crushing unit, bagasse carrier unit, boiler and turbine. All these components are connected in series configuration and some components also have internal redundancy such as unloader is composed in 1-out-of-2: G and turbine 1-out-of-2: G with one standby structures. All these components generally show constant behaviour during repair and failure. So, here all failure and repair rates are considered as exponentially distributed. To fulfill the main objective of the present study, a mathematical model is developed for feeding system and C-K differential equations have been developed for fuzzy availability and profit analysis. In case of imperfect fault detection concept of coverage factor is also used. Numerical results also obtained for a particular case to highlight the importance of the study. This study will be helpful for system designers and management to enhance the productivity.

***KEYWORDS:** Feeding System, Imperfect Coverage, Fuzzy Availability & Runge-Kutta Method*

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Original Article

INTRODUCTION

Sugar is an item of high demand in homes and industry throughout the world, and regardless of health advisory issued for diabetes, like illnesses increases due to sugar, demand and consumption of sugar is still increasing exponentially as human population increases. India is the sixth largest economy in the world with 7.1% growth rate. Three factors, namely agro-based, industry and service sectors are the main contributors in GDP. Agro-based industries stands on the third position. Approximately, 54% population is engaged in the agriculture and related industries according to 2011 census. As India is the largest sugar consumer, may set to record of world’s largest sugar producer in 2018-19. Currently, India is on the second position in sugar production. In spite of the high projected growth rate of sugar industry, it is affected with several numbers of complications alike shortage of cane supply, low electricity supply, old-fashioned technologies, low capability consumption, poor financial support to farmers by government. Due to these snags, the sugar industry is suffering with high operational cost which continually increase their losses. Reliability modelling and analysis of complex industrial systems empower us to find the techniques to enhance the availability and economic behaviour of such systems. Availability is the key measure to analyse the performance of any complex system and it helps the managements in taking immediate decision regarding systems for its functioning so that expenditure cost can be reduced. Many times failure rates of subsystems cannot be completely detected and covered because failure are in-built many times. Availability also helpful to identify the effect of variation in repair rates. A lot of studies have been carried out for availability analysis of sugar systems. First of all Kumar et al. (1988) analysed the availability of feeding

system in the sugar industry. Though the main functioning units have not been taken in the analysis. Kumar et al. (1990) carried out the cost –benefit analysis of a refining unit in a Sugar industry. Kumar et al. (1992) derived availability expression of the crystallization system in the sugar industry under common-cause failure. Agarwal et al. (2011) analyzed the reliability of sugar plant Boolean function technique. Sharma and Khanduja (2013) evaluated the performance measures feeding system in a sugar industry using soft computing techniques. Sinha and Mukhopadhyay(2014) performed a study related to reliability centered maintenance of cone crusher. Kadyan and kumar (2015) studied feeding system in the sugar industry with the help of a supplementary variable technique where failure rates follows an exponential distribution while repair rates are arbitrarily distributed. Kadyan and Kumar (2017) discussed the availability based operational behaviour of B-Pan crystallization system in a sugar plant. It is observed, that a lot of studies carried out for performance evaluation of sugar plants, but all these studies consider only two states of the system either operative or failed. Many times in complex industrial systems, we face the problem of imperfect coverage of failure. The failure not completely identified and removed, but system still working in this state. Such situations can be easily dealt with the fuzzy techniques and methodology given by Zadeh (1965). Utkin and Gurov (1996) suggested a general formal approach for fuzzy reliability analysis. Most of the existing reliability evaluation techniques involves a lot of computational calculation. Some researcher adopted numerical techniques like Runga-Kutta method for solving the differential equations formulated corresponding the developed mathematical model. Kumar and Kumar (2011), Aggarwal et al. (2014), Aggarwal et al. (2016), Kumar and Saini (2017) and Kumar and Saini (2018) used this numerical method based approach along with the concept of fuzzy reliability for performance evaluation of various industrial systems. Keeping in view the above facts, here feeding system is studied as an important unit of a sugar manufacturing plant. It comprises with the help of six components namely unloader, cane carrier, crushing unit, bagasse carrier unit, boiler and turbine. All these components are connected in series configuration and some components also have internal redundancy such as unloader is composed in 1-out-of-2: G and turbine 1-out-of-2: G with one standby structures. All these components generally shows constant behaviour during repair and failure. So, here all failure and repair rates are considered as exponentially distributed. To fulfil the main objective of the present study, a mathematical model is developed for feeding system and C-K differential equations have been developed for fuzzy availability and profit analysis. In case of imperfect fault detection concept of coverage factor is also used. Numerical results also obtained for a particular case to highlight the importance of the study.

System Description

The configuration of feeding system is shown as a reliability block diagram in figure-1. In the initial stage, sugar cane transported from the field to the mill by farmers and dropped on a chain conveyor with the help of unloader. Then cutters cut sugar cane into small pieces and maximum juice is extracted with the help of crushers. The bagasse is sent to the boiler with the help of conveyor belt. Finally, turbines convert steam (obtained from boiler) into electricity. The detailed description of these six subsystems is as follows:

Subsystem A

It is a 1-out-of-2:G redundant nature system. Here, both unloaders are operative. Upon failure of both the unloaders the complete this subsystem fails. And, failure of this causes the shutdown of the sugar plant.

Subsystem B

It consists of two components, one is conveyor belt and other is cutter arranged in series configuration. Failure of

any one component causes the complete failure of sugar plant.

Subsystem C

It squeezes the small pieces of cane and obtain juice as raw material. It works in series with subsystems B, D and E. Its failure results the complete failure of sugar plant.

Subsystem D

It is connected in series with subsystems B, C and E. It's a failure result in the complete failure of the system.

Subsystem E

It is configured in series with subsystems B, C and D. It's a failure result in the complete failure of the system.

Subsystem F

It consists of two identical turbines along with one non-identical turbine. It works in i-out-of-2: G configuration. The complete failure of the system occurred when all the three turbines fail.

Assumptions

- Switch and repairs are perfect.
- The unit works as new after repair.
- All failure and repair times are taken as exponentially distributed.
- Sufficient number of repair facilities available with the system and no failed unit waits for the server for repair.
- No failure happens simultaneously.
- The repair and failure rate of non-identical turbine unit is different from the original turbine unit.

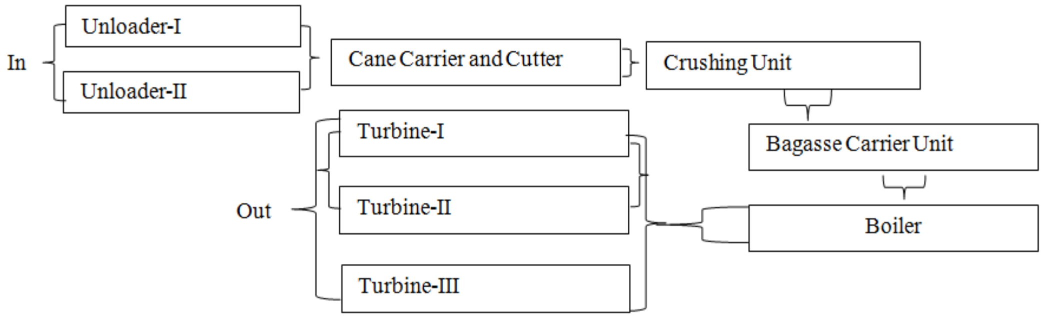

Figure 1: Reliability Block Diagram

Notations

$X_{(OU,FU)}$: Representation of States of the subsystem A and F.

A, B, C, D, E,F: Units working with full capacity

a, b, c, d, e, f: failed states of the units A, B, C, D, E, F

OU: No. of operative units

FU: No. of failed units under repair

$\lambda_i\ (1 \le i \le 7)$: Failure rates of subsystem A, B, C, D, E, F and F_D respectively

$\beta_i\ (1 \le i \le 7)$: repair rates of subsystem A, B, C, D, E, F and F_D respectively

S_i : ithstate of the system

α: Coverage factor having values $0 \le \alpha \le 1$.

$(1-\alpha:)$ fault is not perfectly covered and unit failed.

$P_i(t)$: It denotes the probability that the system is in ith state at time t.

System States

Based on the above assumptions and notations system may be any one of the following states:

$S_1(A_2,B,C,D,E,F_2,F_D)$; $S_2(A_{(1,1)},B,C,D,E,F_2,F_D)$; $S_3(A_2,B,C,D,E,F_{(1,1)},F_D)$;
$S_4(A_{(1,1)},B,C,D,E,F_{(1,1)},F_D)$; $S_5(A_2,B,C,D,E,f_{(0,2)},F_D)$; $S_6(A_2,B,C,D,E,F_{(1,1)},f)$;
$S_7(A_{(1,1)},B,C,D,E,F_{(0,2)},F_D)$; $S_8(A_{(1,1)},B,C,D,E,F_{(1,1)},f)$; $S_9(a_{(0,2)},B,C,D,E,F_2,F_D)$;
$S_{10}(A_{(1,1)},b,C,D,E,F_2,F_D)$; $S_{11}(A_{(1,1)},B,c,D,E,F_2,F_D)$; $S_{12}(A_{(1,1)},B,C,d,E,F_2,F_D)$;
$S_{13}(A_{(1,1)},B,C,D,e,F_2,F_D)$; $S_{14}(A_2,b,C,D,E,F_2,F_D)$; $S_{15}(A_2,B,c,D,E,F_2,F_D)$;
$S_{16}(A_2,B,C,d,E,F_2,F_D)$; $S_{17}(A_2,B,C,D,e,F_2,F_D)$; $S_{18}(A_2,b,C,D,E,F_{(1,1)},F_D)$;
$S_{19}(A_2,B,c,D,E,F_{(1,1)},F_D)$; $S_{20}(A_2,B,C,d,E,F_{(1,1)},F_D)$; $S_{21}(A_2,b,C,D,E,F_{(1,1)},f)$;
$S_{22}(A_2,B,c,D,E,F_{(1,1)},f)$; $S_{23}(A_2,B,C,d,E,F_{(1,1)},f)$; $S_{24}(A_2,B,C,D,E,f_{(0,2)},f)$;
$S_{25}(A_2,B,C,D,e,F_{(1,1)},f)$; $S_{26}(A_2,B,c,D,E,f_{(0,2)},F_D)$; $S_{27}(A_2,b,C,D,E,f_{(0,2)},F_D)$;
$S_{28}(A_2,B,C,d,E,f_{(0,2)},F_D)$; $S_{29}(A_2,B,C,D,e,f_{(0,2)},F_D)$; $S_{30}(A_2,B,C,D,E,f_{(0,2)},f)$;
$S_{31}(a_{(0,2)},B,C,D,E,F_{(1,1)},F_D)$; $S_{32}(A_{(1,1)},b,C,D,E,F_{(1,1)},F_D)$; $S_{33}(A_{(1,1)},B,C,D,E,F_{(1,1)},f)$;
$S_{34}(A_{(1,1)},B,c,D,E,F_{(1,1)},F_D)$; $S_{35}(A_{(1,1)},B,C,d,E,F_{(1,1)},F_D)$; $S_{36}(A_{(1,1)},B,C,D,e,F_{(1,1)},F_D)$;
$S_{37}(A_{(1,1)},B,C,D,E,F_{(0,2)},f)$; $S_{38}(A_{(1,1)},B,C,D,e,F_{(0,2)},F_D)$; $S_{39}(A_{(1,1)},B,C,d,E,F_{(0,2)},F_D)$;
$S_{40}(A_{(1,1)},B,c,D,E,F_{(0,2)},F_D)$; $S_{41}(A_{(1,1)},b,C,D,E,F_{(0,2)},F_D)$; $S_{42}(a_{(0,2)},B,C,D,E,F_{(0,2)},F_D)$;
$S_{43}(A_{(1,1)},B,C,D,e,F_{(1,1)},f)$; $S_{44}(a_{(0,2)},B,C,D,E,F_{(1,1)},f)$; $S_{45}(A_{(1,1)},b,C,D,E,F_{(1,1)},f)$;
$S_{46}(A_{(1,1)},B,c,D,E,F_{(1,1)},f)$; $S_{47}(A_{(1,1)},B,C,d,E,F_{(1,1)},f)$; $S_{48}(A_{(1,1)},B,C,D,E,f_{(0,2)},f)$;
$S_{49}(A_2,B,C,D,e,F_{(1,1)},F_D)$

Out of these states state $S_j;\ j=1,2,3,4,5,6,7,8$ operative states and remaining are the failed.

Formulation and Solution of Mathematical Model

In this section, a mathematical model has been formulated using birth-death process. The C-K differential equation has been obtained and simplified using Runga-Kutta method of fourth order. The differential equations based on state transition diagram are as follows:

$$P_1(t+\Delta t)=[1-2\alpha\lambda_1-2\alpha\lambda_6-(1-\alpha)\lambda_2-(1-\alpha)\lambda_3-(1-\alpha)\lambda_4-(1-\alpha)\lambda_5]P_1(t)\Delta t+\beta_1P_2(t)\Delta t$$
$$+\beta_6P_3(t)\Delta t+\beta_2P_{14}(t)\Delta t+\beta_3P_{15}(t)\Delta t+\beta_4P_{16}(t)\Delta t+\beta_5P_{17}(t)\Delta t$$

$$\frac{P_1(t+\Delta t)-P_1(t)}{\Delta t}=[-2\alpha\lambda_1-2\alpha\lambda_6-(1-\alpha)\lambda_2-(1-\alpha)\lambda_3-(1-\alpha)\lambda_4-(1-\alpha)\lambda_5]P_1(t)+\beta_1P_2(t)$$
$$+\beta_6P_3(t)+\beta_2P_{14}(t)+\beta_3P_{15}(t)+\beta_4P_{16}(t)+\beta_5P_{17}(t)$$

Letting $\Delta t\to 0$, we obtain

$$\frac{dP_1(t)}{dt}+[2\alpha\lambda_1+2\alpha\lambda_6+(1-\alpha)\lambda_2+(1-\alpha)\lambda_3+(1-\alpha)\lambda_4+(1-\alpha)\lambda_5]P_1(t)=\beta_1P_2(t)+\beta_6P_3(t)+\beta_2P_{14}(t)$$
$$+\beta_3P_{15}(t)+\beta_4P_{16}(t)+\beta_5P_{17}(t) \tag{1}$$

$$\frac{dP_2(t)}{dt}+[\beta_1+2\alpha\lambda_6+(1-\alpha)\lambda_1+(1-\alpha)\lambda_2+(1-\alpha)\lambda_3+(1-\alpha)\lambda_4+(1-\alpha)\lambda_5]P_2(t)=\beta_1P_9(t)+$$
$$\beta_2P_{10}(t)+\beta_3P_{11}(t)+\beta_4P_{12}(t)+\beta_6P_4(t)+\beta_5P_{13}(t)+2\alpha\lambda_1P_1(t) \tag{2}$$

$$\frac{dP_3(t)}{dt}+[\beta_6+2\alpha\lambda_1+\alpha\lambda_7+\alpha\lambda_6+(1-\alpha)\lambda_2+(1-\alpha)\lambda_3+(1-\alpha)\lambda_4+(1-\alpha)\lambda_5]P_3(t)=\beta_6P_5(t)$$
$$+\beta_7P_6(t)+\beta_1P_4(t)+\beta_2P_{18}(t)+\beta_3P_{19}(t)+\beta_4P_{20}(t)+\beta_5P_{49}(t)+2\alpha\lambda_6P_1(t) \tag{3}$$

$$\frac{dP_4(t)}{dt}+[\beta_1+\beta_6+\alpha\lambda_6+(1-\alpha)\lambda_1+(1-\alpha)\lambda_2+(1-\alpha)\lambda_3+(1-\alpha)\lambda_4+(1-\alpha)\lambda_5+(1-\alpha)\lambda_7]P_4(t)$$
$$=\beta_6P_7(t)+\beta_1P_{31}(t)+\beta_2P_{32}(t)+\beta_7P_{33}(t)+\beta_3P_{34}(t)+\beta_4P_{35}(t)+\beta_5P_{36}(t)+2\alpha\lambda_1P_3(t)+2\alpha\lambda_6P_2(t) \tag{4}$$

$$\frac{dP_5(t)}{dt}+[\beta_6+2\alpha\lambda_1+(1-\alpha)\lambda_2+(1-\alpha)\lambda_4+(1-\alpha)\lambda_3+(1-\alpha)\lambda_5+(1-\alpha)\lambda_7]P_5(t)=$$
$$\beta_1P_7(t)+\beta_3P_{26}(t)+\beta_2P_{27}(t)+\beta_4P_{28}(t)+\beta_5P_{29}(t)+\beta_7P_{30}(t)+\alpha\lambda_6P_3(t) \tag{5}$$

$$\frac{dP_6(t)}{dt}+[\beta_6+\beta_1+2\alpha\lambda_2+(1-\alpha)\lambda_1+(1-\alpha)\lambda_2+(1-\alpha)\lambda_3+(1-\alpha)\lambda_4+(1-\alpha)\lambda_5+(1-\alpha)\lambda_7]P_6(t)$$
$$=\beta_1P_8(t)+\beta_2P_{21}(t)+\beta_3P_{22}(t)+\beta_4P_{23}(t)+\beta_5P_{25}(t)+\beta_6P_{24}(t)+\alpha\lambda_7P_3(t) \tag{6}$$

$$\frac{dP_7(t)}{dt}+[\beta_1+\beta_6+(1-\alpha)\lambda_1+(1-\alpha)\lambda_2+(1-\alpha)\lambda_3+(1-\alpha)\lambda_4+(1-\alpha)\lambda_5+(1-\alpha)\lambda_7]P_7(t)=$$
$$\beta_1P_{42}(t)+\beta_7P_{37}(t)+\beta_5P_{38}(t)+\beta_4P_{39}(t)+\beta_3P_{40}(t)+\beta_2P_{41}(t)+2\alpha\lambda_1P_5(t)+\alpha\lambda_6P_4(t) \tag{7}$$

$$\frac{dP_8(t)}{dt}+[\beta_1+(1-\alpha)\lambda_1+(1-\alpha)\lambda_2+(1-\alpha)\lambda_3+(1-\alpha)\lambda_4+(1-\alpha)\lambda_5+(1-\alpha)\lambda_6]P_8(t)=$$
$$\beta_5P_{43}(t)+\beta_1P_{44}(t)+\beta_2P_{45}(t)+\beta_3P_{46}(t)+\beta_4P_{47}(t)+\beta_6P_{48}(t)+2\alpha\lambda_1P_6(t) \tag{8}$$

$$\frac{dP_9(t)}{dt}+\beta_1P_9(t)=(1-\alpha)\lambda_1P_2(t) \tag{9}$$

$$\frac{dP_{10}(t)}{dt}+\beta_2 P_{10}(t)=(1-\alpha)\lambda_2 P_1(t) \tag{10}$$

$$\frac{dP_{11}(t)}{dt}+\beta_3 P_{11}(t)=\lambda_3(1-\alpha)P_2(t) \tag{11}$$

$$\frac{dP_{12}(t)}{dt}+\beta_4 P_{12}(t)=\lambda_4(1-\alpha)P_2(t) \tag{12}$$

$$\frac{dP_{13}(t)}{dt}+\beta_5 P_{13}(t)=\lambda_5(1-\alpha)P_2(t) \tag{13}$$

$$\frac{dP_{14}(t)}{dt}+\beta_2 P_{14}(t)=\lambda_2(1-\alpha)P_1(t) \tag{14}$$

$$\frac{dP_{15}(t)}{dt}+\beta_3 P_{15}(t)=\lambda_3(1-\alpha)P_1(t) \tag{15}$$

$$\frac{dP_{16}(t)}{dt}+\beta_4 P_{16}(t)=\lambda_4(1-\alpha)P_1(t) \tag{16}$$

$$\frac{dP_{17}(t)}{dt}+\beta_5 P_{17}(t)=\lambda_5(1-\alpha)P_1(t) \tag{17}$$

$$\frac{dP_{18}(t)}{dt}+\beta_2 P_{18}(t)=\lambda_2(1-\alpha)P_3(t) \tag{18}$$

$$\frac{dP_{19}(t)}{dt}+\beta_3 P_{19}(t)=\lambda_3(1-\alpha)P_3(t) \tag{19}$$

$$\frac{dP_{20}(t)}{dt}+\beta_4 P_{20}(t)=\lambda_4(1-\alpha)P_3(t) \tag{20}$$

$$\frac{dP_{21}(t)}{dt}+\beta_2 P_{21}(t)=\lambda_2(1-\alpha)P_6(t) \tag{21}$$

$$\frac{dP_{22}(t)}{dt}+\beta_3 P_{22}(t)=\lambda_3(1-\alpha)P_6(t) \tag{22}$$

$$\frac{dP_{23}(t)}{dt}+\beta_4 P_{23}(t)=\lambda_4(1-\alpha)P_6(t) \tag{23}$$

$$\frac{dP_{24}(t)}{dt}+\beta_6 P_{24}(t)=\lambda_6(1-\alpha)P_6(t) \tag{24}$$

$$\frac{dP_{25}(t)}{dt}+\beta_5 P_{25}(t)=\lambda_5(1-\alpha)P_6(t) \tag{25}$$

$$\frac{dP_{26}(t)}{dt}+\beta_3 P_{26}(t)=\lambda_3(1-\alpha)P_5(t) \tag{26}$$

$$\frac{dP_{27}(t)}{dt}+\beta_2 P_{27}(t)=\lambda_2(1-\alpha)P_5(t) \tag{27}$$

$$\frac{dP_{28}(t)}{dt}+\beta_4 P_{28}(t)=\lambda_4(1-\alpha)P_5(t) \tag{28}$$

$$\frac{dP_{29}(t)}{dt}+\beta_5 P_{29}(t)=\lambda_5(1-\alpha)P_5(t) \tag{29}$$

$$\frac{dP_{30}(t)}{dt}+\beta_7 P_{30}(t)=\lambda_7(1-\alpha)P_5(t) \tag{30}$$

$$\frac{dP_{31}(t)}{dt}+\beta_1 P_{31}(t)=\lambda_1(1-\alpha)P_4(t) \tag{31}$$

$$\frac{dP_{32}(t)}{dt}+\beta_2 P_{32}(t)=\lambda_2(1-\alpha)P_4(t) \tag{32}$$

$$\frac{dP_{33}(t)}{dt}+\beta_7 P_{33}(t)=\lambda_7(1-\alpha)P_4(t) \tag{33}$$

$$\frac{dP_{34}(t)}{dt}+\beta_3 P_{34}(t)=\lambda_3(1-\alpha)P_4(t) \tag{34}$$

$$\frac{dP_{35}(t)}{dt}+\beta_4 P_{35}(t)=\lambda_4(1-\alpha)P_4(t) \tag{35}$$

$$\frac{dP_{36}(t)}{dt}+\beta_5 P_{36}(t)=\lambda_5(1-\alpha)P_4(t) \tag{36}$$

$$\frac{dP_{37}(t)}{dt}+\beta_7 P_{37}(t)=\lambda_7(1-\alpha)P_7(t) \tag{37}$$

$$\frac{dP_{38}(t)}{dt}+\beta_5 P_{38}(t)=\lambda_5(1-\alpha)P_7(t) \tag{38}$$

$$\frac{dP_{39}(t)}{dt}+\beta_4 P_{39}(t)=\lambda_4(1-\alpha)P_7(t) \tag{39}$$

$$\frac{dP_{40}(t)}{dt}+\beta_3 P_{40}(t)=\lambda_3(1-\alpha)P_7(t) \tag{40}$$

$$\frac{dP_{41}(t)}{dt}+\beta_2 P_{41}(t)=\lambda_2(1-\alpha)P_7(t) \tag{41}$$

$$\frac{dP_{42}(t)}{dt}+\beta_1 P_{42}(t)=\lambda_1(1-\alpha)P_7(t) \tag{42}$$

$$\frac{dP_{43}(t)}{dt}+\beta_5 P_{43}(t)=\lambda_5(1-\alpha)P_8(t) \tag{43}$$

$$\frac{dP_{44}(t)}{dt}+\beta_1 P_{44}(t)=\lambda_1(1-\alpha)P_8(t) \tag{44}$$

$$\frac{dP_{45}(t)}{dt}+\beta_2 P_{45}(t)=\lambda_2(1-\alpha)P_8(t) \tag{45}$$

$$\frac{dP_{46}(t)}{dt}+\beta_3 P_{46}(t)=\lambda_3(1-\alpha)P_8(t) \tag{46}$$

$$\frac{dP_{47}(t)}{dt}+\beta_4 P_{47}(t)=\lambda_4(1-\alpha)P_8(t) \tag{47}$$

$$\frac{dP_{48}(t)}{dt}+\beta_6 P_{48}(t)=\lambda_6(1-\alpha)P_8(t) \tag{48}$$

$$\frac{dP_{49}(t)}{dt}+\beta_5 P_{49}(t)=\lambda_5(1-\alpha)P_3(t) \tag{49}$$

with initial condition:

$$P_j(0)=\begin{cases}1, & if \quad j=1\\ 0, & if \quad j\neq 1\end{cases} \tag{50}$$

The mathematical system of linear differential equations [1-49] along with initial condition provided by equation [50] has been solved by Runge-Kutta method of fourth order. Various reliability measures such as fuzzy availability, fuzzy busy period and profit function have been computed for a duration of 360 days. To highlight the importance of the study variation has been taken in values of failure rate, repair rate and coverage factor. The equation of system effectiveness measures is as follows:

$$A_F=P_1(t)+\sum_{j=2}^{3}\tfrac{8}{9}P_j(t)+\sum_{k=4}^{6}\tfrac{7}{9}P_k(t)+\sum_{l=7}^{8}\tfrac{6}{9}P_l(t) \tag{51}$$

$$B_F=\sum_{m=9}^{13,18-20,49}\frac{1}{9}P_m(t)+\sum_{n=14}^{17}\frac{2}{9}P_n(t)+\sum_{p=21}^{36}\frac{3}{9}P_p(t)+\sum_{r=37}^{48}\frac{4}{9}P_r(t) \tag{52}$$

$$P_F=10000*A_F-500*B_F \tag{53}$$

Performance Analysis

In the present section, numerical results for fuzzy availability and profit of a feeding system have been acquired using equation [51 & 53] by considering constant values for various failure and repair rates. The constant values are

estimated under the suggestions given by sugar plant maintenance personal. The effect of coverage factor on availability and profit function is also measured. By taking arbitrary variation in various repair and failure rates we again check the variation in availability and profit. The fixed set of observations is as follows:

$$\lambda_1 = 0.002,\ \lambda_1 = 0.0002\ ,\lambda_3 = 0.0021,\ \lambda_4 = 0.0001,\ \lambda_5 = 0.0001,\ \lambda_6 = 0.0003,\ ,\lambda_7 = 0.003,$$

$$\beta_1 = 0.015,\ \beta_2 = 0.01\ ,\beta_3 = 0.04,\ \beta_4 = 0.01,\ \beta_5 = 0.015,\ \beta_6 = 0.045,\ \beta_7 = 0.015 \text{ and } \alpha = 0.1, 0.6, 1.$$

The numerical result appended in tables [1-7] show two directional variation in fuzzy availability and profit function. From table 1, it is revealed that if variation occurs in failure rate and fault is not perfectly recovered then fuzzy availability and profit decline rapidly with passes of time and it reaches at 0.9. From table 2, it is observed that availability reaches at 0.10 corresponding to $\alpha = 0.1 \& \lambda_2 = 0.09$. From table 3, it is analysed that availability reaches at 0.17 corresponding to $\alpha = 0.1 \& \lambda_3 = 0.21$. Finally table 7, it is highlighted that availability is 0.919 when $\alpha = 0.1 \& \lambda_7 = 0.9$ because at this stage redundancy policy is opted for operation of the system.

Table 1: Effect of Failure and Repair Rates of Unloader Units on the Fuzzy Availability and Profit of the Feeding Plant with Respect to Time

Coverage Factor	Time (days)	Failure & Repair Rates of Unloader Unit $\lambda_1 \& \beta_1$			Failure & Repair Rates of Unloader Unit $\lambda_1 \& \beta_1$		
		$\beta_1 = 0.015$ $\lambda_1 = 0.002$	$\beta_1 = 0.015$ $\lambda_1 = 0.002$	$\beta_1 = 0.015$ $\lambda_1 = 0.002$	$\beta_1 = 0.015$ $\lambda_1 = 0.002$	$\beta_B = 0.01$ $\lambda_B = 0.2$	$\beta_B = 0.4$ $\lambda_B = 0.0002$
α =1	0	1	1	1	10000	10000	10000
	90	0.979107	0.891432	0.997607	9791.066	8914.317	9976.068
	180	0.97544	0.89138	0.997391	9754.403	8913.797	9973.913
	270	0.974743	0.891355	0.997332	9747.425	8913.547	9973.323
	360	0.974598	0.891331	0.997315	9745.984	8913.313	9973.151
α =0.6	0	1	1	1	10000	10000	10000
	90	0.955796	0.148379	0.969875	9555.037	1353.772	9696.484
	180	0.947233	0.147753	0.966127	9468.626	1347.299	9658.709
	270	0.944432	0.147732	0.964896	9440.311	1347.034	9646.304
	360	0.943459	0.147724	0.964427	9430.477	1346.917	9641.574
α =0.1	0	1	1	1	10000	10000	10000
	90	0.934028	0.1324	0.936963	9335.14	1191.194	9364.736
	180	0.925128	0.096118	0.929458	9245.368	822.1256	9289.099
	270	0.922115	0.094022	0.927017	9214.96	800.7233	9264.494
	360	0.920968	0.093794	0.926094	9203.378	798.3723	9255.199

Table 2: Effect of Failure and Repair Rates of Cane Carrier and Cutter Units on the Fuzzy Availability and Profit of the Feeding Plant with Respect to Time

Coverage Factor	Time (days)	Failure & Repair Rates of Cane Carrier and Cutter Unit $\lambda_2 \& \beta_2$			Failure & Repair Rates of Cane Carrier and Cutter Unit $\lambda_2 \& \beta_2$		
		$\beta_2 = 0.01$ $\lambda_2 = 0.0002$	$\beta_2 = 0.01$ $\lambda_2 = 0.0002$	$\beta_2 = 0.01$ $\lambda_2 = 0.0002$	$\beta_2 = 0.01$ $\lambda_2 = 0.0002$	$\beta_B = 0.01$ $\lambda_B = 0.2$	$\beta_B = 0.4$ $\lambda_B = 0.0002$
α =1	0	1	1	1	10000	10000	10000
	90	0.979107	0.979107	0.979107	9791.066	9791.066	9791.066
	180	0.97544	0.97544	0.97544	9754.403	9754.403	9754.403
	270	0.974743	0.974743	0.974743	9747.425	9747.425	9747.425
	360	0.974598	0.974598	0.974598	9745.984	9745.984	9745.984
α =0.6	0	1	1	1	10000	10000	10000

	90	0.955796	0.226423	0.960144	9555.037	2200.773	9598.891
	180	0.947233	0.213781	0.953279	9468.626	2072.003	9529.61
	270	0.944432	0.213215	0.951149	9440.311	2065.344	9508.08
	360	0.943459	0.212979	0.950443	9430.477	2062.23	9500.947
α =0.1	0	1	1	1	10000	10000	10000
	90	0.934028	0.109631	0.943456	9335.14	1026.611	9430.166
	180	0.925128	0.109008	0.938133	9245.368	1020.147	9376.446
	270	0.922115	0.108958	0.936506	9214.96	1019.491	9360.015
	360	0.920968	0.108935	0.9359	9203.378	1019.116	9353.898

Table 3: Effect of Failure and Repair Rates of Crushing Unit on the Fuzzy Availability and Profit of the Feeding Plant with Respect to Time

Coverage Factor	Time (days)	Failure & repair rates of crushing unit λ_3 & β_3			Failure & repair rates of crushing unit λ_3 & β_3		
		$\beta_3 = 0.04$ $\lambda_3 = 0.0021$	$\beta_3 = 0.04$ $\lambda_3 = 0.0021$	$\beta_3 = 0.04$ $\lambda_3 = 0.0021$	$\beta_3 = 0.04$ $\lambda_3 = 0.0021$	$\beta_B = 0.01$ $\lambda_B = 0.2$	$\beta_B = 0.4$ $\lambda_B = 0.0002$
α =1	0	1	1	1	10000	10000	10000
	90	0.979107	0.979107	0.979107	9791.066	9791.066	9791.066
	180	0.97544	0.97544	0.97544	9754.403	9754.403	9754.403
	270	0.974743	0.974743	0.974743	9747.425	9747.425	9747.425
	360	0.974598	0.974598	0.974598	9745.984	9745.984	9745.984
α =0.6	0	1	1	1	10000	10000	10000
	90	0.955796	0.318609	0.973512	9555.037	3130.03	9733.73
	180	0.947233	0.317224	0.965134	9468.626	3114.42	9649.231
	270	0.944432	0.316398	0.962259	9440.311	3105.063	9620.189
	360	0.943459	0.315893	0.961263	9430.477	3099.32	9610.122
α =0.1	0	1	1	1	10000	10000	10000
	90	0.934028	0.173734	0.972864	9335.14	1672.64	9726.579
	180	0.925128	0.173491	0.964073	9245.368	1669.923	9637.92
	270	0.922115	0.173366	0.960761	9214.96	1668.447	9604.501
	360	0.920968	0.173288	0.9595	9203.378	1667.492	9591.777

Table 4: Effect of Failure and Repair Rates of Bagasse Carrier Unit on the Fuzzy Availability and Profit of the Feeding Plant with Respect to Time

Coverage Factor	Time (days)	Failure & Repair Rates of Bagasse Unit λ_4 & β_4			Failure & Repair Rates of Bagasse Unit λ_4 & β_4		
		$\beta_4 = 0.01$ $\lambda_4 = 0.0001$	$\beta_4 = 0.01$ $\lambda_4 = 0.0001$	$\beta_4 = 0.01$ $\lambda_4 = 0.0001$	$\beta_4 = 0.01$ $\lambda_4 = 0.0001$	$\beta_B = 0.01$ $\lambda_B = 0.2$	$\beta_B = 0.4$ $\lambda_B = 0.0002$
α =1	0	1	1	1	10000	10000	10000
	90	0.979107	0.979107	0.979107	9791.066	9791.066	9791.066
	180	0.97544	0.97544	0.97544	9754.403	9754.403	9754.403
	270	0.974743	0.974743	0.974743	9747.425	9747.425	9747.425
	360	0.974598	0.974598	0.974598	9745.984	9745.984	9745.984
α =0.6	0	1	1	1	10000	10000	10000
	90	0.955796	0.764985	0.957968	9555.037	7630.748	9576.943
	180	0.947233	0.706536	0.950249	9468.626	7040.594	9499.045
	270	0.944432	0.690202	0.94778	9440.311	6875.44	9474.09
	360	0.943459	0.685507	0.946939	9430.477	6827.877	9465.593
α =0.1	0	1	1	1	10000	10000	10000
	90	0.934028	0.584442	0.938726	9335.14	5811.728	9382.496
	180	0.925128	0.519916	0.931595	9245.368	5161.144	9310.55
	270	0.922115	0.507954	0.929263	9214.96	5040.442	9287.005
	360	0.920968	0.505634	0.928378	9203.378	5016.978	9278.076

Table 5: Effect of Failure and Repair Rates of Boiler on the Fuzzy Availability and Profit of the Feeding Plant with Respect to Time

Coverage Factor	Time (days)	Failure & Repair Rates of Boiler λ_5 & β_5			Failure & Repair Rates of Boiler λ_5 & β_5		
		$\beta_5 = 0.015$ $\lambda_5 = 0.0001$	$\beta_5 = 0.015$ $\lambda_5 = 0.0001$	$\beta_5 = 0.015$ $\lambda_5 = 0.0001$	$\beta_5 = 0.015$ $\lambda_5 = 0.0001$	$\beta_B = 0.01$ $\lambda_B = 0.2$	$\beta_B = 0.4$ $\lambda_B = 0.0002$
α =1	0	1	1	1	10000	10000	10000
	90	0.979107	0.979107	0.979107	9791.066	9791.066	9791.066
	180	0.97544	0.97544	0.97544	9754.403	9754.403	9754.403
	270	0.974743	0.974743	0.974743	9747.425	9747.425	9747.425
	360	0.974598	0.974598	0.974598	9745.984	9745.984	9745.984
α =0.6	0	1	1	1	10000	10000	10000
	90	0.955796	0.671401	0.957583	9555.037	6686.945	9573.061
	180	0.947233	0.632247	0.94945	9468.626	6291.162	9490.991
	270	0.944432	0.626602	0.946751	9440.311	6233.755	9463.714
	360	0.943459	0.625526	0.945803	9430.477	6222.666	9454.125
α =0.1	0	1	1	1	10000	10000	10000
	90	0.934028	0.465047	0.937888	9335.14	4608.378	9374.046
	180	0.925128	0.439965	0.929872	9245.368	4355.327	9293.181
	270	0.922115	0.438245	0.927055	9214.96	4337.837	9264.753
	360	0.920968	0.437998	0.925947	9203.378	4335.244	9253.571

Table 6: Effect of Failure and Repair Rates of Turbine Units on the Fuzzy Availability and Profit of the Feeding Plant with Respect to Time

Coverage Factor	Time (days)	Failure & Repair Rates of Turbine λ_6 & β_6			Failure & Repair Rates of Turbine λ_6 & β_6		
		$\beta_6 = 0.045$ $\lambda_7 = 0.0003$	$\beta_6 = 0.045$ $\lambda_7 = 0.0003$	$\beta_6 = 0.045$ $\lambda_7 = 0.0003$	$\beta_6 = 0.045$ $\lambda_7 = 0.0003$	$\beta_B = 0.01$ $\lambda_B = 0.2$	$\beta_B = 0.4$ $\lambda_B = 0.0002$
α =1	0	1	1	1	10000	10000	10000
	90	0.979107	0.774779	0.980651	9791.066	7747.792	9806.515
	180	0.97544	0.771271	0.977174	9754.403	7712.71	9771.741
	270	0.974743	0.770627	0.976543	9747.425	7706.271	9765.428
	360	0.974598	0.770506	0.976427	9745.984	7705.063	9764.275
α =0.6	0	1	1	1	10000	10000	10000
	90	0.955796	0.721645	0.956667	9555.037	7195.433	9563.778
	180	0.947233	0.699294	0.948202	9468.626	6965.531	9478.35
	270	0.944432	0.690676	0.945434	9440.311	6876.768	9450.376
	360	0.943459	0.686326	0.944474	9430.477	6831.914	9440.673
α =0.1	0	1	1	1	10000	10000	10000
	90	0.934028	0.806652	0.934153	9335.14	8049.322	9336.396
	180	0.925128	0.781395	0.925259	9245.368	7790.761	9246.682
	270	0.922115	0.771938	0.922247	9214.96	7693.845	9216.29
	360	0.920968	0.767076	0.9211	9203.378	7643.987	9204.713

Table 7: Effect of Failure and Repair Rates of Duplicate Turbine Unit on the Fuzzy Availability and Profit of the Feeding Plant with Respect to Time

Coverage Factor	Time (days)	Failure and Repair Rate Effect of Duplicate Turbine Unit λ_7 & β_7			Failure and Repair Rate Effect of Duplicate Turbine Unit λ_7 & β_7		
		$\beta_7 = 0.015$ $\lambda_7 = 0.003$	$\beta_7 = 0.015$ $\lambda_7 = 0.003$	$\beta_7 = 0.015$ $\lambda_7 = 0.003$	$\beta_7 = 0.015$ $\lambda_7 = 0.003$	$\beta_B = 0.01$ $\lambda_B = 0.2$	$\beta_B = 0.4$ $\lambda_B = 0.0002$
α =1	0	1	1	1	10000	10000	10000
	90	0.979107	0.97096	0.979358	9791.066	9709.602	9793.585
	180	0.97544	0.959224	0.975864	9754.403	9592.24	9758.64
	270	0.974743	0.951223	0.975236	9747.425	9512.233	9752.362
	360	0.974598	0.944433	0.975123	9745.984	9444.327	9751.229
α =0.6	0	1	1	1	10000	10000	10000
	90	0.955796	0.949726	0.955915	9555.037	9493.883	9556.242
	180	0.947233	0.934277	0.947443	9468.626	9337.869	9470.743
	270	0.944432	0.92522	0.944678	9440.311	9246.307	9442.802
	360	0.943459	0.918723	0.94372	9430.477	9180.615	9433.113
α =0.1	0	1	1	1	10000	10000	10000
	90	0.934028	0.933518	0.934031	9335.14	9330.01	9335.177
	180	0.925128	0.924145	0.925136	9245.368	9235.454	9245.444
	270	0.922115	0.920771	0.922124	9214.96	9201.401	9215.054
	360	0.920968	0.919345	0.920978	9203.378	9186.993	9203.48

CONCLUSIONS

In this section concluding remarks have been appended based on numerical computations given in the previous section to help the system designers and production engineers to enhance the production of the sugar plants. It is observed from tables 1-7 that in case of low coverage of the failure fuzzy availability and profit of the system decline rapidly. The subsystems, namely unloader, cane carrier and crusher units are very sensitive with respect to failure rate. As the failure rate increases and time passes, availability and profit decreases. Redundancy of turbine unit play a key role in enhancing the availability and profit of sugar plant. By providing more redundant components to various subsystems in suitable configuration, the availability and profit can be improved.

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